Renewable and Sustainable Energy Reviews 28 (2013) 767–776

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Structural change and carbon emission of rural household energy consumption in Huantai, northern China

Long Liang [a,b], Wenliang Wu [a,*], Rattan Lal [b], Yanbin Guo [a]

[a] College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China
[b] Carbon Management and Sequestration Center, The Ohio State University, Columbus, OH 43210, USA

A R T I C L E I N F O

Article history:
Received 16 May 2011
Received in revised form
26 March 2013
Accepted 21 July 2013
Available online 7 September 2013

Keywords:
Rural household
Energy consumption
Structural change
Carbon emission
Strategy

A B S T R A C T

Huantai, a typical high-yielding agricultural county in the northern developed region of China and as a microcosm of China's rural area, is chosen as a case study to analyze the structural change and carbon (C) emission of rural household energy consumption. During the last 30 years, the per capita consumption and emission increased from 329 kg standard coal equivalent (kg ce) and 783.6 kg CO_2 to 638.4 kg ce and 1582.5 kg CO_2, with the average annual growth rates of 3.2% and 3.5%, respectively. Among four activities (lighting, cooking, heating, and recreation), cooking and heating account for $>$ 70–95% at different times, and recreation is the fastest-growing activity. The current annual growth rates for recreational consumption and emission are 133.3% and 115.5%, respectively. In the context of energy structure, the proportion of nonrenewable energy increased from 15.7% in 1980 to 87.7% in 2009. Increase in income and changes in lifestyle are the two key factors affecting energy consumption and C emission. And this trend is endangering the sustainable development of rural areas and further China's development. Thus, it is necessary to develop new renewable energy strategy and explore new low-C developing mode both for local and central governments. At the level of Huantai county, appropriate strategies include improving use-efficiency of straw, developing large and medium-sized biogas digester, and harvesting solar energy. At the level of central government, developing biomass, rural biogas industry and solar energy have large potentials. It is necessary to continue to promote energy-saving stoves and small energy facilities, such as small wind power and hydropower stations in rural areas. But how to realize high-speed development and low-C emission in the process of urbanization is a major challenge in China at present and in the future.

Contents

* Corresponding author. Tel./fax: +86 10 62736537.
E-mail address: wuwenl@cau.edu.cn (W. Wu).

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http://dx.doi.org/10.1016/j.rser.2013.07.041

1. Introduction

Climate change may strongly impact the human society, economy and the environment. Consequently, development of low-carbon(C) fuel sources is gaining momentum globally [1–3]. In the “twelfth five-year plan”(the most important plan designed and completed by the government) of China, low-C and green development are emphasized and will become important components of its economy. Towards an effort to develop a low-C society, there is a growing focus on cities and industry. Nonetheless, low-C villages and towns must also be taken into account, especially in China. There are >940 million rural residents in China, among which about 750 millions keep permanent residency status in villages and their daily life is also an integral part of the low-C society [4–6]. In the past, the quantity of rural energy consumption was drastically less than that in the cities. The majority of rural households were mainly dependent on traditional biomass (i.e., crop residues/straw and firewood) as household energy source. Thus, C emission from fossil-fuels was low, and emissions from rural households were often neglected. With the rapid development of the economy, however, the structure of household energy consumption has greatly changed and rural C emissions are progressively increasing. Indeed, non-renewable and commercial energy sources constitute a considerable proportion of total energy use in some developed rural areas [7–9]. Thus, it is necessary to analyze the structural change and emission of rural households at spatial and temporal scales, to identify basic principles and trends, and adopt corresponding measures to prevent rural areas from becoming a major C source.

This manuscript is a case study of the Huantai county of Shandong province, a typical agricultural region in developed area. It is based on an analysis of representative rural household survey and diverse sources of aggregate statistics. It explores the structural change and C emission of household energy use from 1980 to 2009. The results presented can be used as an important reference for other regions of northern China, which are also in the process of rapid modernization. The data presented are also important to identify researchable priorities to balance the energy supply and demand, formulate energy policy, and create eco-environment in rural northern China.

2. Materials and methods

2.1. The study area

Huantai county is located in the center of the Shandong province, which is part of the North China Plain (NCP), located between 36°51′50″ and 37°06′00″N, and 117°50′00″ and 118°10′40″E (Fig. 1). The study covers an area of 520 km^2, and ~0.5 million people, consisting of 0.41 million in rural communities. This region has a typical continental monsoonal climate, characterized by an average annual temperature of 12.5 °C, with long cold winters. The soil parent material mainly consists of mountain diluvium and Yellow River alluvial deposits, which developed into loam soils classified as Calcaric Fluvisols [10]. This region is the primary food-producing area of China. More than 80% of agricultural land use between 1990 and 2010 comprised of the cropping system involving winter wheat (*Triticum aestivum* L.) and summer corn (*Zea mays* L.). Agronomic productivity in 1990 was >15 Mg/ha of grains across the entire region. Thus, Huantai became the first grain county in northern China, and earned the title of “Granary of North Lu”. Modern, intensive livestock breeding is also widely practiced, while sporadic, personal livestock breeding is rapidly diminishing [10]. Along with the rapid development of industry and agriculture in recent years, there are many employment opportunities for rural laborers, created by local town and village businesses and the construction industry. Consequently, rural per capita net annual income increased from 88 RMB (Chinese Yuan) in 1978 to 9745 RMB in 2010. Yet, the contribution of agriculture to the total GDP decreased from 49.4% in 1983 to $<5\%$ in 2009, and $>80\%$ of peasant's income is derived from non-agricultural industries [10].

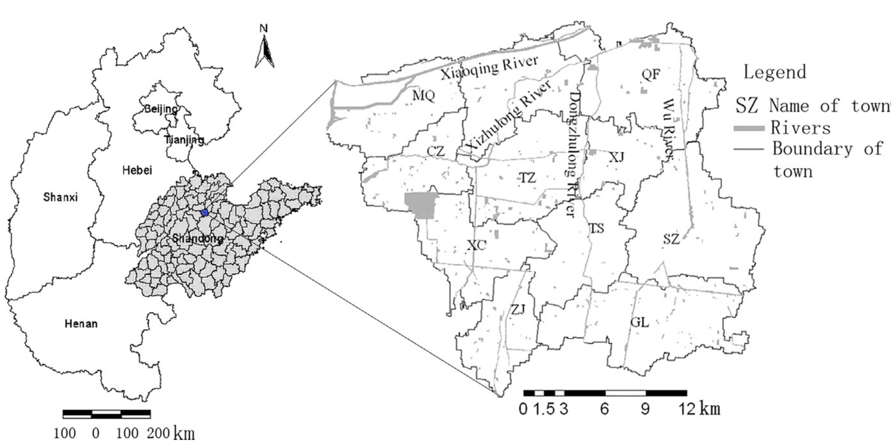

Fig. 1. Geographic location of the study area in Huantai County. Abbreviations: CZ—Chengzhuang town; GL—Guoli town; JJ—Jingjia town; MQ—Maqiao town; QF—Qifeng town; TS—Tangshan town; XC—Xingcheng town; XJ—Xingjia town; ZJ—Zhoujia town.

2.2. Data collection and analysis

With the exception of the data for the 1980s, which was derived from a nationwide survey [11], all data concerning rural household energy consumption in Huantai county were obtained through site surveys, which are also more reliable and accurate. The data for the year 1989 was obtained through a cooperative sample survey and an on-the-spot investigation by the Energy Sector Management Assistance Program [12]. Data for the years 2005 and 2009 were obtained using questionnaires circulated by China Agricultural University's experiment station in Huantai. There are 11 towns in Huantai county, and additional survey was conducted in 5 towns and 11 villages. A random stratified sampling method was adopted, and questionnaires were distributed to 220 families. The 1989 questionnaire was altered slightly for use in 2005 and 2009 to credibly assess the current rural household energy consumption in the Huantai county. Relevant coefficients of standard coal conversion and C emission used are presented in Table 1. The method to calculate corn stover consumption also followed the same index [10], and the investigated communities are the same villages and small towns surveyed in 2006 and 2010. The Excel program was adapted to conduct statistical analysis. To begin with, the inspecting questionnaires removed some exceptional invalid questions to ensure the effectiveness of the survey. Secondly, the input data were used to calculate the mean values of consumption and emission. Thirdly, the data were analyzed to determine structure of the energy source and excess C emission. In the meanwhile, a portion of the macro-data was also collected from the Huantai Statistical Yearbooks and China Rural Energy Statistical Data [13].

An assessment of the energy-consuming appliances was conducted to analyze the relationship among energy consumption, C emission and lifestyle changes (Table 2). It is not possible to provide correct data for 1980 because of the lack of relative statistical data. Thus, a baseline was developed by using a similar survey conducted for urban population over the same time [16].

Table 1
Index of standard coal conversion and carbon emission of all types of energy. *Source:* [14,15].

Energy type	Unit	Standard coal efficiency (kg ce/unit)	Carbon emission efficiency (kg CO_2/unit)
Coal	kg	0.7143	1.786
Gasoline	kg	1.4714	3.096
Kerosene	kg	1.4571	3.200
Diesel	kg	1.4571	3.250
LPG	kg	1.7143	3.182
Electricity	kWh	0.346	0.997
Straw	kg	0.529	1.247
Firewood	kg	0.571	1.436
Biogas	m^3	0.714	1.173
Solar	m^2	130	0

Note: in north China, most of electricity comes from coal-fired plants. Thus, relative coefficient of coal-fired plant is taken for electricity emission.

3. Results

3.1. Energy consumption and carbon emission

The rural household energy consumption and C emissions in Huantai county have been increasing during the past 30 years (since 1980). The per capita consumption increased from 329 kg of standard coal equivalent (kg ce; 1 kg ce = 7000 kcal) in 1980 to 638.4 kg ce in 2009. Compared to national average growth, (Fig. 2), during the 1980s, the growth rate of energy consumption in Huantai county was much higher. The Huantai county was basically at the level of national average in 2005. In 2009, however, it was above the national average for rural consumption. Such a trend means that household energy consumption is rapidly increasing in China's rural areas. In developed districts (such as Huantai), however, the mean growth rate is much higher than that of the national average. In the meanwhile, the C emissions also increased from 783.6 kg CO_2 in 1980 to 1582.5 kg CO_2 in 2009, with an annual growth rate of 3.2% and 3.5%, respectively (Tables 3 and 4). Simultaneously, the structures of energy consumption and C emission have also changed drastically. In addition, there is a close relationship among consumption, emissions, and lifestyle changes (Table 2).

3.1.1. Nonrenewable energy sources

The nonrenewable energy consumptions [including electricity, liquified petroleum gas (LPG), gasoline and kerosene] have increased from 51.7 kg ce in 1980 to 560.1 kg ce in 2009, and the proportion of the total increased from 15.7% to 87.7%. In contrast, the consumption of renewable energy (i.e., straw, biogas and solar) decreased from 277.3 kg ce in 1980 to 78.3 kg ce in 2009 and its proportion of the total decreased from 84.3% to 12.3%. Similarly,

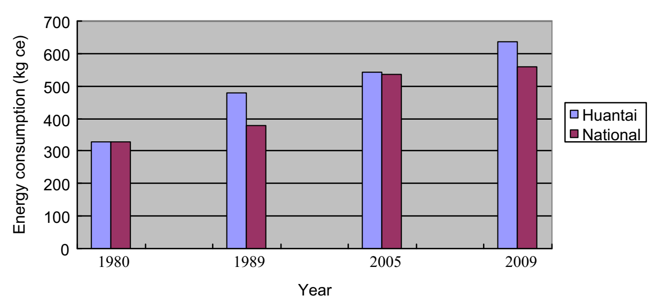

Fig. 2. Energy consumption of national rural average and Huantai district.

Table 2
Quantity of primary energy-consuming appliances per 100 rural households from 1980 to 2009.

Year	Motorcycle	Sedan	Washing machine	Refrigerator	Color TV	Electrical cooker	Air-conditioner	Motor bicycle	Computer	Electrical fan	Solar water heater
1980	–	–	–	–	–	–	–	–	–	–	–
1989	1	0	11	0	10	0	0	0	0	75	0
1998	31	0	45	24	79	30	0	0	0	110	0
2005	57	3	79	48	116	60	22	12	13	224	8
2009	65	9	92	72	122	197	34	83	28	157	40

Note: from 1985, the local government of Huantai county began to investigate the situation of rural household economy. Thus, there are no statistical data about 1980. In fact, reform and opening-up began in 1980, but China's rural households were still in extreme poverty. According to one investigation of primary energy-consuming appliances per 100 urban household in Zhejiang province in 1981, the quantity of refrigerator, color TV and washing machine was only 0.53.0.53 and 1.32, respectively [16]. Simultaneously, the supplemental investigation in Huantai county showed energy-consuming appliance in general households in 1980 was almost zero, but these data were from estimation and the memories of local peasants.

Table 3
Per capita rural household energy consumption of different energy types.

Energy	1980		1989		2005		2009	
	Energy (kg ce)	%	Energy (kg ce)	%	Energy (kg ce)	%	Energy (kg ce)	%
Electricity	3.29	1	15.02	3.14	54.34	10.00	114.35	17.91
LPG	0	0	3.81	0.80	16.19	2.98	14.27	2.24
Coal	46.72	14.2	295.02	61.67	352.82	64.92	385.75	60.43
Gasoline	0	0	0	0	26.34	4.85	45.68	7.16
Kerosene	1.65	0.5	0.69	0.14	0	0	0	0
Straw	277.3	84.3	163.32	34.14	93.74	17.25	67.77	10.62
Biogas	0	0	0.50	0.10	0	0	3.76	0.59
Solar	0	0	0	0	0	0	6.80	1.07
Total	328.96	100	478.36	100	543.43	100	638.38	100

Table 4
Per capita CO_2 emissions from diverse energy sources from 1980 to 2009.

Energy	1980		1989		2005		2009	
	kg CO_2	%	kg CO_2	%	kg CO_2	%	kg CO_2	%
Electricity	9.48	1.21	43.28	3.68	156.58	11.64	329.50	20.82
LPG	0	0.00	7.07	0.60	30.05	2.23	26.49	1.67
Coal	116.82	14.91	737.65	62.76	882.17	65.58	964.51	60.95
Gasoline	0	0	0	0	55.42	4.12	96.12	6.07
Kerosene	3.62	0.46	1.52	0.13	0	0.00	0.00	0
Straw	653.67	83.42	384.99	32.76	220.97	16.43	159.75	10.10
Biogas	0	0	0.82	0.07	0	0	6.18	0.39
Solar	0	0	0	0	0	0	0	0
Total	783.59	100	1175.33	100	1345.20	100	1582.54	100

in 2009, the magnitude of C emission from nonrenewable energy amounted to 1416.6 kg CO_2 compared with only 129.9 kg CO_2 in 1980. In the meanwhile, the emission from renewable energy reduced from 653.7 kg CO_2 in 1980 to 165.9 kg CO_2. This trend implies that nonrenewable or commercial energy is progressively playing more and more important role in peasant's life in the Huantai county.

Coal consumption has become the major factor in nonrenewable energy and C emissions. It has greatly surpassed other energy sources, accounting for 14.2% of total use in 1980 and increasing to 60% by 1989. In addition, electricity, oil products, and LPG use also increased dramatically. However, the rate of increase of electricity is higher than that of LPG. This trend is attributed to two principal factors. One, coal is the main energy source in China, because its availability and use are extremely convenient. In northern China, rural households need a lot of fuel for home heating in winter, which has made coal the first choice of consumption. Two, with the reform and open-door policy of China since 1978, the incomes of peasants have increased and their lifestyle and energy consumption pattern drastically changed. In 1980s, the household energy was almost entirely used only for cooking and home heating. After 1990, however, the use of energy-consuming products (such as household appliances) has increased rapidly (Table 2), and recreational activities have also played a vital part in the daily activities of rural life.

3.1.2. Renewable energy source

There are two obvious features about renewable energy use in Huantai county. One, the quantity of straw/stover consumption and emission is decreasing, and has decreased from 277.3 kg ce and 653.7 kg CO_2 in 1980 to 67.8 kg ce and 159.8 kg CO_2 in 2009, respectively. Two, clean energy sources (i.e., biogas and solar energy) have emerged strongly, and renewable energy has exhibited diverse trends. The proportion of straw consumption and emission reduced sharply from 84.3% and 83.4% in 1980 to 10.6% and 10.1%, respectively. Principal reasons for this trend are adoption of no-till (NT) and straw retention mulch farming practices over the last two decades (since 1990) with strong adoption by local farmers. But corn straw and cobs are still used as household fuel for cooking, especially by relatively-poor families. Concerning diverse range of renewable energy in use since 1988, the local government began to explore and utilize renewable energy including straw gasification, solar energy, and biogas etc. [17]. Through repeated exploration and practice until 2006, the local government decided to widely popularize solar energy and biogas. However, the results of this survey showed that domestic biogas has not been widely adopted by the local households in the Huantai county.

3.2. Change of consumption and emission of energy end-use

For the purpose of this report, consumption of energy is divided into four types: lighting, cooking, home heating and recreation. Among these, electricity and coal are also divided into different types according to its relative consumption. The results of this survey show that, solar energy is generally used for recreational purposes. From the standpoint of energy end-use, during the past 30 years (since 1980), the consumption and emission have also greatly changed (Tables 5 and 6).

3.2.1. Energy consumption and carbon emission for lighting

The energy consumption and C emission trends for lighting have changed from highly diverse to only a few sources and the consumption increased initially but eventually decreased. In general, there are two trends of energy consumption and emission by lighting. Between 1980 and 2005, the per capita consumption and emission for lighting increased from 5.0 kg ce and 13.1 kg CO_2 to 19.4 kg ce and 55.9 kg CO_2,

Table 5
Structure of per capita energy end-use types from 1980 to 2009.

Behaviors	Energy source	1980		1989		2005		2009	
		Energy (kg ce)	%	Energy (kg ce)	%	Energy (kg ce)	%	Energy (kg ce)	%
Lighting	Electricity	3.3	66.6	11.3	93.5	19.4	100	8.6	100
	Kerosene	1.7	33.4	0.7	5.7	0	0	0	0
	Biogas	0	0	0.1	0.8	0	0	0	0
	Subtotal	5.0	100	12.1	100	19.4	100	8.6	100
Cooking	Straw	166.4	94.7	160.2	53.4	93.7	39.5	67.8	31.0
	Electricity	0	0	0	0	4.2	1.8	14.9	6.8
	Coal	9.4	5.3	135.8	45.3	123.1	51.9	117.9	54
	LPG	0	0	3.8	1.3	16.2	6.8	14.3	6.5
	Biogas	0	0	0.4	0.1	0	0	3.8	1.7
	Subtotal	175.8	100	300.2	100	237.3	100	218.6	100
Home heating	Coal	37.4	25.2	159.2	98.1	229.7	100	267.8	100
	Straw	110.9	74.8	3.2	1.9	0	0	0	0
	Subtotal	148.3	100	162.3	100	229.7	100	267.8	100
Recreation	Electricity	0	0	3.7	100	30.7	53.8	90.9	63.4
	Gasoline	0	0	0	0	26.3	46.2	45.7	31.9
	Solar	0	0	0	0	0	0	6.8	4.7
	Subtotal	0	0	3.7	100	57.1	100	143.4	100
Total		**329.0**		**478.4**		**543.4**		**638.4**	

Table 6
Carbon emission of per capita energy end-use types from 1980 to 2009.

Behaviors	Energy source	1980		1989		2005		2009	
		kg CO_2	%	kg CO_2	%	kg CO_2	%	kg CO_2	%
Lighting	Electricity	9.5	72.4	32.6	95.1	55.9	100	24.7	100
	Kerosene	3.6	27.7	1.5	4.4	0	0	0	0
	Biogas	0	0	0.2	0.5	0	0	0	0
	Subtotal	13.1	100	34.3	100	55.9	100	24.7	100
Cooking	Straw	392.3	94.4	377.6	52.1	221	38.7	159.8	30.1
	Electricity	0	0	0	0	12.2	2.1	42.8	8.1
	Coal	23.4	5.6	339.7	46.9	307.8	53.9	294.9	55.6
	LPG	0	0	7.1	1	30.1	5.3	26.5	5
	Biogas	0	0	0.7	0.1	0	0	6.2	1.2
	Subtotal	415.6	100	724.9	100	571.1	100	530.1	100
Home heating	Coal	93.4	26.3	398	98.2	574.3	100	669.6	100
	Straw	261.4	73.7	7.4	1.8	0	0	0	0
	Subtotal	354.9	100	405.4	100	574.3	100	669.6	100
Recreation	Electricity	0	0	10.7	100	88.5	61.5	262	73.2
	Gasoline	0	0	0	0	55.4	38.5	96.1	26.8
	Solar	0	0	0	0	0	0	0	0
	Subtotal	0	0	10.7	100	143.9	100	358.1	100
Total		**783.6**		**1175.3**		**1345.2**		**1582.5**	

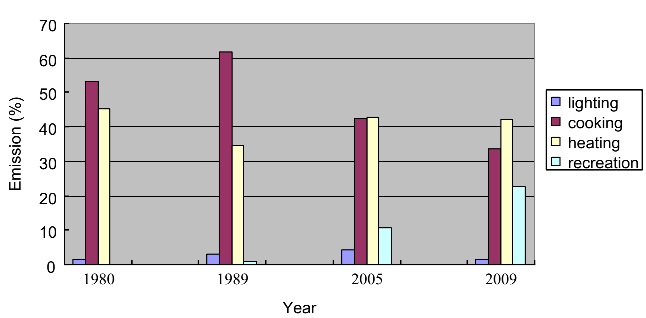

Fig. 3. Emission proportion of different activities.

respectively. During 2009, the amounts further decreased to 8.6 kg ce and 24.7 kg CO_2. But the proportion of consumption and emission for lighting are rather small compared with that of the total. During 2005, the peak electricity-related consumption and emission amounted to merely 3.6% and 4.2% of total, respectively (Fig. 3). There are two principal reasons for this trend. First, after rural power network reconstruction in 1980s, the supply of electricity became more stable and convenient. Therefore, lighting energy consumption changed almost entirely to electricity, while kerosene and biogas use greatly diminished. Second, during the 1980s and 1990s, with the growth of income and increased area of the household, the demand for lighting also increased. In addition, using filament light bulb in most of rural families also added to the overall energy consumption. With the development of technology and the adoption of energy-saving lamps, the attendant consumption and emission also decreased during 2000s. In the future, the consumption and emission by lighting is projected to decrease with increase in technological advances. Nonetheless, the impact on total consumption and emission reduction may be rather modest.

3.2.2. Cooking energy consumption and carbon emission

Energy consumption and C emission have changed from simple to diverse sources, which increased initially but decreased gradually. This trend is the main feature of energy consumption and C emission for cooking. In 1980, straw/stover was the principal source of cooking energy, and coal was a secondary source. In fact, the rural households' cooking energy fundamentally depended on straw/residue, and its proportion reached 94.7% because of the lack of energy and purchasing power at that time. In 1989, LPG and biogas were used for cooking, and the quantity of LPG steadily increased. However, the use of biogas ceased for a time in 2006, because private livestock breeding in this region disappeared during the early 2000s. At the same time, electricity was used as cooking energy in most rural families. In 2009, straw, coal, LPG, electricity, biogas were all used for cooking, representing extremely diverse energy sources.

In 1980, per capita consumption and emission from cooking was 175.8 kg ce and 415.6 kg CO_2, respectively. In 1989, the quantities increased to 300.2 kg ce and 724.9 kg CO_2, then reached the peak with the growth of 35.0% and 74.4%, respectively. In 2005, however, the per capita consumption and emission decreased to 237.3 kg ce and 571.1 kg CO_2 and further reduced to 218.6 kg ce and 530.1 kg CO_2, with a strong decreasing trend over time. Straw and crop residues have played an important role and still form an important component of the cooking energy use. In 1980, consumption and emission from straw combustion amounted to 166.4 kg ce and 392.3 kg CO_2, which was $>94\%$ of the total energy use for cooking. In 1989, the amount of straw consumption stabilized but the proportion of energy use decreased to 50%. Along with the adoption of straw retention/mulch farming practices and the improvement of purchasing power of rural households, the quantity and proportion of energy use from straw decreased further during the 2000s. However, because of the traditional use of corn cobs as fuel, especially, in many relatively poor families, crop residues are still a major component of cooking energy source, and the proportion of total energy consumption from straw amounted to 30% in 2009. According to the trends observed and lifestyle, the use of straw will continue for a long time, but its relative proportion will decrease progressively with time.

With the decrease in use of corn stover, coal becomes the most important factor affecting emission. In 1980, consumption and emission of coal were only 9.4 kg ce and 23.4 kg CO_2, respectively. In 1989, however, consumption and emission increased by a factor of 15 to 135.8 kg ce and 339.7 kg CO_2. Between 1989 and 2009, because of other energy sources involved, the magnitude regressively decreased to 117.9 kg ce and 294.9 kg CO_2, respectively. On the contrary, however, the proportion of energy use increased from $\sim 45\%$ in 1989 to 55% in 2009. The trend analysis showed that coal was the most important cooking energy in the Huantai county in 2009. From 1989 onward, the use of electricity, LPG and biogas for cooking also increased progressively. Among these, electricity use increased rapidly, use of LPG remained stable, but that of biogas still constitutes a low proportion of the total cooking energy consumption in the Huantai county.

3.2.3. Energy consumption and carbon emission for home heating

In northern China, home heating is an important part of rural household energy consumption. With the exception of 1989, the consumption and emission for heating exceeded 40% of the total energy use. Unlike cooking, however, home heating consumption remained relatively stable (Fig. 3). The statistical analysis of the data showed that energy use for home heating was initially dominated by traditional biomass energy, which gradually shifted to coal. In the meantime, the amount of coal consumption and the related emission increased rapidly. The proportion of biomass for heating energy was nearly 75% in 1980, but hardly 2% in 1989, because coal became the primary energy source. From 2005 onward, coal has been the only source of energy for home heating. In 2010, however, some families began using electricity as energy source for home heating. During 1980s and early 1990s, most rural families were primarily dependent on simple coal stoves which heated a small area and had low heating efficiency. During 2000s, however, a range of large-diameter energy-saving coal stoves with radiator heating became the main sources for home heating. Meanwhile, with the improvement of living standards, the attendant consumption and emission progressively increased along with rapid growth because of excessive reliance on coal. Between 1980 and 2009, the annual growth rate of consumption and emission from coal consumption was $>20\%$. Therefore, coal was the primary source of energy consumption and C emission in rural households.

3.2.4. Recreational energy consumption and carbon emission

The fastest growth rate, among the four consumption activities, is in the recreation sector. The per capita consumption and emission for recreation increased from zero in 1980 to 143.4 kg ce and 358.1 kg CO_2 in 2009, respectively. During the past 30 years (since 1980), the average annual growth rate has been 133.3% and 115.5%. The principal source for recreational energy includes electricity and gasoline. In 2009, however, solar energy also became a part of this mix. The principal reason of increase in consumption and emission from recreation is the rapid increase in the use of household appliances. In 1980, rural families had no recreational appliances. In 1989, washing machine and CTV were used by 10% of the rural families. From 1998 onward, as income increased and the quality of life improved, all kinds of modern facilities (e.g., private vehicles, color TVs, washing machines, refrigerators, air conditioners, motorcycles) were adopted by rural families. Surprisingly, even sedan car also began to enter the rural communities. The direct result of this affluence is the shift in energy consumption from a small amount of electricity use to larger amounts of electricity and oil products, along with an attendant and sharp increase in emission. Predictably, recreational consumption and C emission will progressively increase at high growth rate for a long time.

4. Discussion

4.1. Unsustainability of fossil energy and sustainable development

China's population is large and diverse. Thus, energy and natural resources are relatively insufficient. Average per capita availability is much lower than the world average. China's Energy Situation and Policy (2007) reported that, the per capita mineable reserves of oil, natural gas, and coal were equal to 8.5%, 4.7%, and 50% of the global average levels [18], respectively. Since the policy reform and opening up to the modernization course since 1978, China has experienced the fastest rate of development in the world with an average annual growth rate of 9.8%. Consequently, the energy consumption is also growing rapidly. In 2006, the amount of primary energy consumption was 2.46 Pg ce. In 2010, the energy consumption increased to >3 Pg ce, and may increase to 4.31 Pg ce by 2015 [19]. In fact, the rural household energy consumption is also growing but at a relatively lower rate. In 1995, primary energy consumption by rural population was 0.38 Pg ce, and the proportion from biomass was 60.7% [20]. In 2006, the quantity and ratio amounted to 0.5 Pg ce and 55%, respectively, with average annual growth rate of 2.9% [21]. Based on the Huantai experience, from 1980 to 2009, the average annual growth rate has been 3.2%. The data presented in this report showed that the estimated primary energy consumption of rural family was 0.56–0.57 Pg ce in 2010. For a long time, most of the

energy source for rural families was biomass. Thus, energy consumption calculations about rural household energy use did not take this factor into account towards computing the statistical data on total energy use. In 2009, 50% of the energy consumption of the rural households came from nonrenewable energy sources, and in now developed regions such as the Huantai county the nonrenewable energy amounts to ~90% (Fig. 4). It is obvious that, in modern society, the rural communities may follow the city lifestyles, and continue to pursue the conventional model of high economic growth based on a high energy consumption. Furthermore, rural communities also depend excessively on nonrenewable energy use. Yet, the growth rate of nonrenewable energy cannot meet all the energy needs, making this model and path unsustainable [22,23]. Therefore, shortage of energy source is the major challenge facing rural China at present and in the future.

4.2. Structure of energy source and trend

The Huantai county belongs to a prosperous region, and its rate of growth is higher than that of the national rural average in China. In 2009, national rural per capita net income was just over 5000 RMB. In Huantai county, the rural per capita income is >9000 RMB [24], and it is located in the NCP. Therefore, to some extent, it is the microcosm of China's rural area, and especially represents northern rural society's future trends about energy consumption and C emissions. Compared to the national mean average (Fig. 4) [25], the amount of commercial energy consumption (including coal, gasoline and electricity) is 2.0, 2.3 and 7.4 times more than the national average use in 2009. On the contrary, renewable energy (including straw, biogas and solar energy) consumption constitutes only 12.2% of the total energy use. This trend means that, with the improvement of living standards in rural households, farmers depend more and more on fossil-fuel energy to improve the quality of life. Further, the lifestyle is likely to change even more in the foreseeable future, along with strong impact on C emissions and the environmental impact. This transformation, once again, validates the energy ladder theory [26]. In fact, this trend is not only evident in China but also in other emerging economics [27,28]. Therefore, the central and western regions of China will probably follow the same trend during the next two decades, especially so if China maintains its high rate of development and does not adopt any effective counter measures in the near future.

4.3. Carbon emissions and environmental deterioration

The energy consumption and structure in the Huantai county during the last 30 years has undergone drastic changes. Consequently, C emissions increased rapidly from 783.6 kg CO_2 in 1980 to 1582.5 kg CO_2 in 2009, at the annual growth rate of 3.5%. In 1980, 83.4% of the CO_2 source was crop residues and firewood use. In 2009, the proportion of CO_2 emission from biomass decreased to 10.5% of the total. Consequently, C emission from fossil-fuel reached the value of 89.5% (Table 7). International Energy Agency (IEA) reported that, the proportional use of renewable energy in China decreased from 41.1% in 1971 to 20% in 2000 and to 16.2% in 2010, and is projected to decrease to 13.2% by 2020 and 11.0% by 2030. However, the proportional use of renewable energy is predicted to increase again by 2030 [29]. Analyses of Huantai's data indicate that this projection is credible, and perhaps Huantai, as one of the developed regions compared to other parts of China, is the first region to achieve the lowest level of biomass use in household energy consumption.

Anthropogenic emissions related to use of fossil-fuels are getting more attention because they disrupt the global C budget. On the contrary, CO_2 emissions from biomass have not been taken into account at regional or national scale, because in theory, it is the product of photosynthesis and is a C-neutral energy source. However, there are high risks of using crop residues as fuel to agricultural ecosystems and human health. Furthermore, emission of soot (black carbon) has more drastic impact on radioactive forcing than hitherto assumed [28]. Further, straw removal exacerbates the loss of soil organic carbon (SOC) in agricultural lands and consequently contributes to accelerated erosion and soil fertility decline [30]. Furthermore, the energy use efficiency is <10%. Thus, there is a serious waste of this precious resource. Farmers have to burn a large quantity of crop residues to produce the desired quantity of energy, which further exacerbates C emissions.

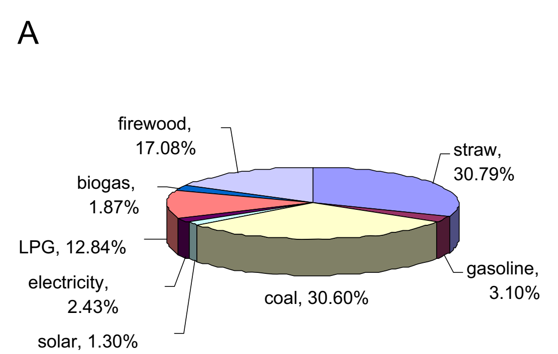

Fig. 4. Structure of household energy consumption in rural China and Huantai county in 2009. *Note***:** (A) is the national rural average use in China, and (B) refers specifically to the Huantai county.
Source: [25].

Table 7
Proportion of nonrenewable and renewable resource from 1980 to 2009.

Source	1980		1989		2005		2009	
	Energy kg CO_2	%	Energy kg CO_2	%	Energy kg CO_2	%	Energy kg CO_2	%
Non-resource	129.9	16.6	789.5	67.2	1124.2	83.6	1416.6	89.5
Re-resource	653.7	83.4	385.8	32.8	221	16.4	165.9	10.5
Total	783.6	100	1175.3	100	1345.2	100	1582.5	100

Furthermore, traditional biomass (i.e., straw and firewood) are burnt directly, which not only emit greenhouse gases (GHGs) but also produce other environmental pollutants [e.g., SO_2, CO, total suspended particulates (TSP)]. Whereas the former cause global warming, the latter detrimentally affect indoor environments and jeopardize human health [31,32]. The shift from traditional biomass to commercial energy (such as in the Huantai county) may reduce local pollution, especially particulate emissions, and also generate important benefits to public health. However, its replacement by commercial fuels results in overall gains in energy efficiency but a severe decline in energy intensity [28]. Therefore, an excessive reliance on nonrenewable energy is unsustainable. Thus, it is necessary to develop renewable and clean sources of energy.

4.4. Renewable energy and rural development

Developing renewable energy is one of the main policy measures adopted by the China's National Climate Change Programme. Accordingly, wind, solar, biomass and geothermal are being considered among the major energy sources of the future [33]. At the same time, a broader perspective is required that takes into account social, economic, and environmental factors associated with rural life. In China especially in the midwestern regions, straw is still an important energy source and there are 110 million rural households using traditional stoves. The energy use efficiency can be improved from 10% to 30% by using energy-saving stove, which means 55 Tg of the standard coal equivalent could be saved and the amount of soot and CO_2e emission reduction would be 528 Gg and 138 Tg, respectively [25]. In the meanwhile, the Huantai county is undergoing the second transformation, mainly because of the energy shortage. Crop residues still account for 10% of the total energy use, and the per household coal consumption will decline by ~20% and 400 RMB could be saved through adoption of improved energy-saving stoves.

Domestic household biogas digester construction is the principal project of renewable energy in the rural areas. It is making a good progress in less developed central and western regions [34]. By 2009, the numbers of household biogas digesters and large and medium-sized projects are 35.07 million and 22,570, respectively. And the quantity of biogas estimated at 13.08 billion m^3 is equivalent to saving of 21 Tg ce and GHG emissions reduction of 51 Tg CO_2e [25]. Some estimates show that the maximum GHG emission reduction per household biogas digesters could be 2.0–4.1 Mg CO_2e per year [35]. In 2008, a nationwide investigation involving 13 provinces about Chinese rural household biogas production was completed and the results showed that the average biogas yield of Chinese rural household was 450 m^3, under an average working period of 9 months per year. Biogas contributed 18% to household energy consumption, but provided 40% effective heat per capita. The employed biogas digester substituted 15% of the commercial energy used in rural household, especially coal. In households with a biogas facility, energy consumption per capita was only 419.56 kg ce, which was 16% lower than non-biogas families. Annually, 559–938 RMB would be created from a biogas facility, and 0.314 ha woodland could be protected after biogas use [34]. Some case studies about large and medium-sized farms in Shandong and Shanxi province showed that the advanced anaerobic system reduced greenhouse gas emission by 81–86%, and the economic benefits have been increased by 5–7% [36,37]. As for Huantai, there is a long history of biogas use, but most households have abandoned this technique because of several problems such as high labor requirement, material shortage, high cost, inconvenience, etc. While the local government is aggressively promoting the use of biodigesters, its use was $<10\%$ in 2009. Thus, it is a serious waste of the precious resource. On the contrary, some intensive breeding farms are interested in developing a biogas industry to manage wastes, but lack funds and technological support. Therefore, constructing large-scale biogas programs at the regional level is an effective means to develop this industry.

In addition, solar energy is a clean energy resource and becoming more and more popular in China. The coverage of solar water heating panels was 135 million m^2 at the end of 2009, and this is equivalent of saving 17.55 Tg ce and reducing GHG emission by 45.63 Tg CO_2 [38]. In Huantai, its adoption rate is as much as 40% because it is clean and convenient, but it merely represents 1.07% of the total energy consumption. The survey conducted herein shows that rural households do not reject renewable energy. However, they prefer a convenient, efficient, clean and economic energy source. Thus, exploring new modes of renewable energy use in rural area is an important option to achieve long-term sustainable development in China.

4.5. Urbanization and low-C developing mode

The population of China in 2010 was 1.37 billion, of which 0.75 billion (55%) lived in rural areas. China's urbanization was 45.7% in 2009 [6]. By 2050, the population of China will be 1.5 billion, of which 70% will live in urban centers [39]. Thus, ~0.3 billion rural inhabitants will become urban citizens during the next 40 years. In fact, urbanization of rural population is in full swings in different regions of China for a range of reasons [40]. The per capita C emission in China increased from 2.2 Mg CO_2 in 1990 to 4.1 Mg CO_2 in 2005 and to 6.2 Mg CO_2 in 2011 [41]. While the per capita emissions at present are far below those of America and Europe, China is the world's fastest-growing economy. At the same time, city dwellers primarily depend on nonrenewable energy. In contrast, the proportion of renewable energy (including straw, firewood, biogas and solar energy) use in rural areas is $>50\%$. Therefore, urbanization is accelerating C emission in long-term because of the drastic transformation of lifestyles. To some degree, urbanization is converting rural areas into a large C source, which will increase even more drastically in the future. This trend is also global. Thus, exploring new modes of renewable energy, according to regional conditions, to achieve low-C transformation in the process of urbanization is a great challenge for China and the world.

Over the past three decades, China has dramatically expanded its power supply in both urban and rural areas. As a result of this expansion, the country has made significant progress in providing rural communities with reliable energy services, and there are some matured modes in rural areas about renewable energy resources. In the future, those modes will continue to play important roles in rural low-C development. Firstly, comprehensive biomass (including straw and firewood) use is becoming popular in different regions. It is estimated that the amount of straw harvested is 700 Tg annually. Excluding that which is directly returned to fields, there is 350 Tg of straw that can be used as fuel in China's rural areas. Using energy-saving stoves to improve energy use efficiency is a way to solve energy shortages. Additionally, in the past 10 years, the technology for converting agricultural waste into straw densification briquetting fuel (SDBF) of high-grade and high density has been lucubrated. It is important that SDBF technology is developed for agricultural ecological environment, and rural living conditions and agricultural sustainable development [42].

Secondly, at present and in future, developing a biogas industry in rural areas is still an important mode to promote renewable energy sources, reduce C emission, and receive economic benefits. Over the past 30 years, the development of biogas for farm household use has been through quite a long process with different stages (including pilot and launching, technical

breakthrough and improvement of procedure and technologies, rapid development, and construction). Popularization and usage of biogas for farm households have been successful as a whole. A basic construction unit featuring 'three change for one pool' (biogas generating pool and reconstruction of kitchen, toilet and barn) has been formed. In addition, according to the natural and economic conditions in different regions as well as the practical need in adjusting the industrial structure of agriculture, ecological energy development modes of biogas for rural household use has been creatively developed with the southern 'pig–biogas–fruit' (combination of pig raising with biogas and fruit trees planting) and the northern 'four in one' (combination of pig raising with biogas, vegetable planting and sunlight greenhouse building) as typical modes. At present, with the constant increase of government investment, the extensive central and west regions of China are making efforts to develop renewable energy resources and ecological agriculture with biogas. Data shows that 80 million rural households are suitable for the development of domestic biogas. Thus, there is a great prospect about the biogas industry. As for developed and east districts, such as Huantai county, the rapid development of intensive breeding makes construction of large and medium-sized regional biogas program a sensible choice. The mode of combination of company with household is becoming commonplace in some areas.

Thirdly, developing solar energy in rural area has great potential to reduce C emission. Including solar water heaters, solar stoves and passive solar houses have been widely adopted in rural areas. Similarly, the prospect for photovoltaic (PV) technology development is strong. Most parts of China receive high levels of solar insolation, averaging 1668 kWh/m^2 annually. In fact, 1200 kWh/m^2 is considered a reasonably high level of insolation [43]. With the acceleration of urbanization, developing low-C building is also an important way to achieve sustainable development. Some new modes of solar energy use such as passive solar building, the solar water heating system into high-rise residences, the domestic multifunctional solar assisted heat pump system, etc., have recently emerged [44]. In addition, small wind-power and micro-hydropower development in extensive rural regions has been a major source of clean energy.

5. Conclusions

Huantai county can be seen as the microcosm of China'a rural area. During the last 30 years (since 1980), the per capita energy consumption and C emissions increased from 329 kg ce and 783.6 kg CO_2 in 1980 to 638.4 kg ce and 1582.5 kg CO_2 at an annual average growth rate of 3.2% and 3.5%, respectively. Of the four activities in 1980, cooking and heating comprised of the major consumptions and emission, 53% and 45%, respectively. In 2009, cooking and heating contributed merely 34% and 42% of consumption and emission. Meanwhile, recreational consumption and emission are the fastest-growing sectors, with an annual mean growth rate of 133.3% and 115.5%, respectively. In Huantai county, nonrenewable and renewable energy sources were 16.6% and 83.4% in 1980, respectively. In 2009, the number was 89.5% and 10.5%. Increases in income and changes in lifestyle are the two key factors affecting energy consumption and C emission. Due to its excessive dependence on fossil-fuel, the consumption and emission will continue to increase in the future, while exacerbating both the energy demand and its environmental impacts.

In the level of Huantai county, while coal and electricity are becoming the major energy sources, and are also the contributors of increases in emissions of GHGs, the use of diverse energy sources is necessary and inevitable in order to achieve sustainable development. In the short-term, promoting energy-conserving stoves and improving use efficiency are important strategies. In the long-term, developing the SDBF technology and adopting a collective heating system are also effective measures to reduce coal consumption and C emission. Domestic household biogas is incompatible with Huantai's circumstances, and is difficult to promote. But developing large and medium-sized biogas digesters may be a good strategy. Solar energy is widely accepted and has bright prospects due to its convenience. However, its single-function limits its share of the total energy use. Therefore, it is necessary to conduct further research and expand its functions. Furthermore, low-C building should be implemented under site-specific scenarios in the process of urbanization.

In the level of central government, China should further actively develop rural biogas industry and make better use of biomass and solar energy, so as to provide clean and renewable energy for the rural populations. It will continue popularizing energy-saving stoves and small energy facilities, such as small wind power and hydropower stations in rural areas. How to realize high-speed development and low-C emission of rural area is a great challenge in China.

Acknowledgments

The work is done under the auspices of the CAU-UCR International Center for Ecology and Sustainability of China Agricultural University and the Carbon Management and Sequestration Center of the Ohio State University, and help received from staff especially Ph.D. student A. Gelaw and Lady T. Colson is greatly appreciated.

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